Long-term effects of organic and conventional farming on soil erosion

John P. Reganold*, Lloyd F. Elliott† & Yvonne L. Unger‡

* Department of Agronomy and Soils, Washington State University, Pullman, Washington 99164, USA
† Agricultural Research Service, US Department of Agriculture, Pullman, Washington 99164, USA
‡ Department of Plant and Soil Sciences, University of Maine, Orono, Maine 04469, USA

Conventional, intensive tillage farming systems have greatly increased crop production and labour efficiency. But, serious questions are being raised about the energy-intensive nature of these systems and their adverse effects on soil productivity and environmental quality[1,2]. This concern has led to an increasing interest in organic farming systems because they may reduce some of the negative effects of conventional agriculture on the environment[3,4]. We compare the long-term effects (since 1948) of organic and conventional farming on selected properties of the same soil. The organically-farmed soil had significantly higher organic matter content, thicker topsoil depth, higher polysaccharide content, lower modulus of rupture and less soil erosion than the conventionally-farmed soil. This study indicates that, in the long term, the organic farming system was more effective than the conventional farming system in reducing soil erosion and, therefore, in maintaining soil productivity.

Organic farming differs from conventional farming mainly in tillage methods, crop rotations, fertilizer applications, and pest control methods. Whereas conventional farming systems depend on chemical fertilizers and pesticides, organic farming systems avoid or largely exclude their use by relying upon crop rotations, manuring, mechanical cultivation, organic fertilizers, and biological pest control to maintain soil productivity, supply plant nutrients, and control pests[5].

We studied two adjacent winter wheat (*Triticum aestivum*) fields from two farms, one organically managed and the other conventionally managed, containing a study area where all soil-forming factors as described by Jenny[6], except management, were equal. The study area was made up of Naff silt loam (fine-silty, mixed, mesic Ultic Argixeroll), a dark-coloured, well-drained soil which formed under grass in deep deposits of loess mixed with some thin layers of volcanic ash[7]. Typically, Naff soils have a silt loam surface A1 horizon 20–46 cm thick, overlying an A2 or AB horizon of heavy silt loam. The next layer is a strong, silty clay loam Bt or argillic B horizon (a layer of clay accumulation that is significantly denser than the layer(s) above). The slope of the study area was ~6.5%, but ranged from 5 to 8%.

The two farms were situated 30 km south of Spokane, Washington, USA, in the northern part of the productive dryland winter wheat area referred to as the Palouse. The organic farm was a 320 ha wheat farm identified in the US Department of Agriculture report on organic farming[5] as a farm which had been managed without the use of inorganic fertilizers and only limited use of pesticides (that is spot spraying mainly around field edges and in ditches) since the farm was first ploughed in 1909. The organic farm relied upon green manure crops, crop rotations, and native soil fertility for plant nutrients. The organic farm used a crop rotation of winter wheat (*T. aestivum*), spring pea (*Pisum sativum*) and Austrian winter pea (*P. sativum* spp. *arvense* L. Poir). The Austrian winter peas, which were used as a green manure crop, were replaced by summer fallow in dry years (about every sixth year).

The adjoining 525 ha conventional farm was first cultivated in 1908 but did not begin receiving recommended rates of fertilizers and pesticides until 1948 and the early 1950s, respectively (A. Clausen, personal communication). Winter wheat received N, P, and S applications at 96, 34, and 16 kg ha^{-1}, respectively; spring peas received no fertilizer. The conventional farm generally used a crop rotation of winter wheat (*T. aestivum*) and spring pea (*P. sativum*). Summer fallow was used when necessary for water conservation in dry years.

Compared to the conventional farm management system, the organic system had similar tillage operations when growing peas but fewer tillage operations when growing wheat (no fertilizer operation) and when green manuring. The two management systems had similar crop varieties but differed in fertilizer use, crop rotations, and managers. Average winter wheat yields for the past five years were 8% lower on the organic farm than on the conventional farm, but almost 13% higher than on a second

Table 1 Estimates of recent winter wheat yields

Year	Organic farm (tons ha^{-1})	Conventional farm (tons ha^{-1})	Second conventional* farm (tons ha^{-1})
1982	4.79	4.85	4.05
1983	4.25	4.92	3.91
1984	4.25	5.26	4.05
1985	4.38	4.72	3.98
1986	4.85	4.72	3.98
Average	4.50	4.90	3.99

Estimates for all three farms were derived from the farm managers and the USDA Agricultural Stabilization and Conservation Service in Spokane, Washington. Both conventional farms were adjacent to the organic farm.

* This second conventional farm of 328 hectares used an annual cropping rotation (no fallow) of winter wheat, Steptoe barley and spring pea.

Table 2 Mean values of soil properties

Soil property	Organic farm	Conventional farm
Surface soil colour	10YR 4/2	10YR 5/2, 5/3
Polysacchride content (g kg^{-1} soil)	1.13*	1.00
Moisture content (%)	15.49†	8.98
Modulus of rupture (MPa)	1.61×10^{-2}	1.98×10^{-2}*
Surface texture	Silt loam	Silt loam
Subsoil (Bt) texture	Silty clay loam	Silty clay loam
Bulk density (mg m^{-3})	0.98	0.95
Surface (A1) horizon thickness (cm)	39.80*	36.68
Depth to argillic horizon (cm)	55.60†	39.80

The initial study area consisted of a pair of transects, with ten sample points in each transect. Each transect was parallel to and 4.5 m from the boundary line (between the farms) and 55 m long. Soil samples were collected in the summer of 1985 from the surface 0–10 cm for all 20 samples and analysed for bulk density and soil water content. At the same 20 sample points, deeper soil cores (7 cm diameter) to at least 100 cm in depth were analysed in the field for soil texture, colour, thickness of A1 horizon and depth to the Bt horizon. From the texture and colour changes evident in the soil core profiles, thicknesses of the surface horizons to the underlying argillic (Bt) horizons were determined. A *t*-test was used to compare the bulk densities, moisture contents, thickness of the A1 horizons, and depths to the Bt horizons between the two farms. The study area also consisted of four plots (6.1 × 9.1 m), two on each side of, and 6.1 m away from the boundary line between the farms. Twenty surface soil samples (0–10 cm depth) were collected from a grid pattern superimposed on each of the four plots for a total of 80 samples. These samples were analysed for modulus of rupture using the Reeve method[26] and polysaccharide content according to the anthrone method proposed by Brink *et al.*[27] and modified by Metting and Rayburn[28]. Statistical comparisons of the results were made using ANOVA.

* <0.05.
† <0.01.

conventional farm (with similar soils) adjacent to the organic farm (Table 1).

The soil properties investigated are shown in Table 2. The surface layer of the organically-farmed soil was darker (10YR 4/2 or dark greyish brown) than the surface layer of the conventionally-farmed soil (10YR 5/2 or greyish brown, and 10YR 5/3 or brown), indicating significantly higher organic matter levels in the organically-farmed soil. An earlier study[8] with the two farms showed that the organically-farmed soil had significantly higher levels of organic carbon. These results support the conclusion that organic farmers can, and generally do, achieve higher organic matter levels in their soils than do conventional farmers[9,10].

Organic matter has a profound impact on soil quality; it encourages granulation, increases water storage, nutrient supply, and soil organism activity, and improves soil fertility and productivity[11,12]. An earlier study[8] with these two farms showed that the organically-farmed Naff soil had significantly higher levels of urease, phosphatase, and dehydrogenase (soil enzymes) and significantly higher microbial biomass. We found that the organically-farmed soil also had significantly higher polysaccharide content than the conventionally-farmed soil (Table 2). Polysaccharides, some of which are produced by soil microorganisms, serve as active binding agents in soil aggregate formation, and are involved in aggregate stability[13,14].

Moisture contents were significantly higher in the organically-farmed soil than in the conventionally-farmed soil (Table 2), which may be attributed to the higher organic matter levels of the organically-farmed soil. As moisture-release curves from an earlier study[15] were similar for both soils, it may be inferred that the water potential of the organically-farmed soil was higher than that of the conventionally-farmed soil at the time of sampling. The organically-farmed soil had a significantly lower modulus of rupture (an index related to the hardness of surface crusting), indicating that seedling emergence could be enhanced in the organically-farmed soil. Surface horizons of both farms had silt loam textures, whereas the argillic horizons had silty clay loam textures (Table 2). Bulk densities of the organically and conventionally-farmed soils were not significantly different.

The surface horizon of the organically-farmed soil was significantly thicker (by 3 cm) than the surface horizon of the conventionally-farmed soil. Topsoil thickness, represented by the depth of the soil layers (A1 and A2 horizons) to the subsoil argillic horizon, was almost 16 cm greater in the organically-farmed than conventionally-farmed soil. These differences, especially the large difference in topsoil depth, are attributed to significantly greater soil losses due to erosion on the conventionally-farmed soil between 1948 and 1985.

Erosion not only reduces the surface horizon thickness but also, more significantly, brings the subsoil layer(s) (in this case the argillic layer) nearer to the surface (Fig. 1). Despite the higher erosion rate of the conventionally-farmed Naff soil, its surface (A1) horizon thickness was only 3 cm thinner than that of the organically-managed soil. This was due to its continual mixing with the A2 horizon by ploughing, and the addition of fresh organic matter from crop residues. But the A2 layer was much thinner, so the amount of productive topsoil was dramatically less (by 16 cm) on the conventionally-farmed soil. This loss of topsoil was due to water and tillage erosion.

This conclusion is supported by the results of water erosion research conducted on the same study area[15], examining both the organic and conventional farms using the Alutin method to measure the cross-sections of rills, in a year when both farms were in winter wheat. Water erosion was found to be 8.3 ton ha^{-1} on the organic field and 32.4 ton ha^{-1} on the conventional field, almost a fourfold difference.

The rate of water erosion on the conventional field is very close to the average annual rate of water erosion of 31.5 ton ha^{-1} in the Palouse area, one of the more erosive areas in the United States[16] and is almost three times the maximum soil-loss tolerance value of 11.2 ton ha^{-1} yr^{-1} for Naff soils, whereas the rate of water erosion on the organic farm is <75% of the maximum tolerance value[17]. Soil loss tolerance, called the '*T* value', is the maximum rate of soil erosion that can occur without reducing long-term crop productivity or environmental quality of a specific soil[18]. Our data indicate that the long-term productivity of the organically-farmed Naff soil is being maintained, whereas that of the conventionally-farmed Naff soil is being reduced because of high rates of soil erosion.

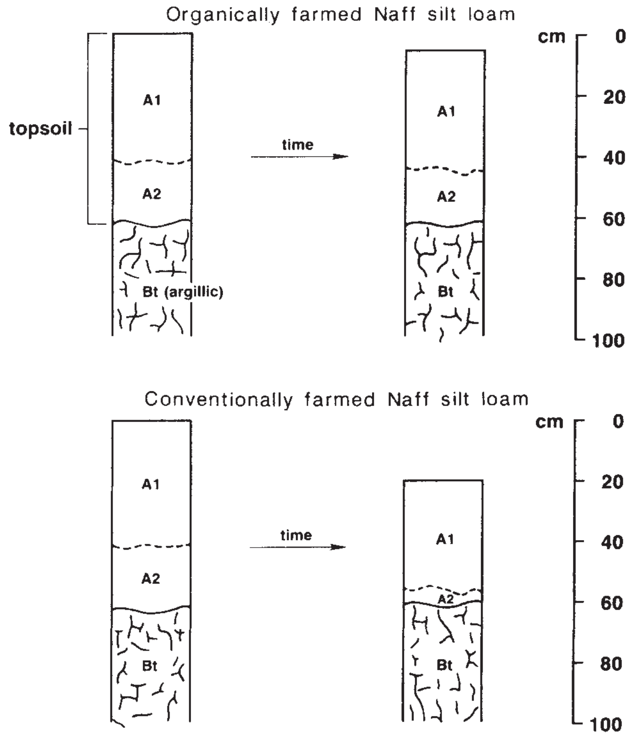

Fig. 1 Organically and conventionally farmed soil losses due to water erosion between 1948 and 1985. The organically farmed Naff silt loam has lost about 5 cm of topsoil, while the conventionally farmed Naff silt loam has lost about 21 cm of topsoil leaving a 16 cm difference in topsoil thickness between the two soils in 1985. The A2 horizon for Naff soils is characteristically only slightly lower in organic matter than the A1 horizon. So its mixing with the thinning A1 by ploughing, plus the addition of organic matter from crop residues, helps maintain a fairly normal A1 horizon until the A2 horizon is completely depleted. Topsoil losses were extrapolated from both field measurements of water erosion[15] and topsoil thickness (Table 2). The effects of tillage erosion on topsoil thickness were not included.

Loss of topsoil by erosion has been shown to reduce organic matter, fine clays, available water-holding capacity, plant rooting depth, soil productivity, and crop yields[19,20]. At current rates of water and tillage erosion for typical Naff and similar soils of varying slope positions under conventional farming systems, it has been projected that all the topsoil will be lost in 50 yr, exposing the denser, less fertile subsoil argillic horizons[21]. Also, crop yields will be reduced at zero topsoil to 2.4 ton ha^{-1} and 1.8 ton ha^{-1} for Naff soil on Class III and IV sites respectively[21]. Our study area is on a Class III Naff soil.

These projected declines in yield ignore any concurrent yield increases due to improved technology over this 50-yr period. But uncontrolled erosion can substantially decrease the benefits from improved plant varieties and cultural practices, which have the greatest potential for increasing winter wheat yields on deep, relatively uneroded topsoils[22]. At some point, the increasing yield reduction from erosion may exceed the diminishing yield increase due to technical progress.

The difference in erosion rates between the organic and conventional farms was most probably due to their different crop rotation systems. Only the organic farm included a green manure legume crop in the third year of rotation, and it had fewer tillage operations. Comparisons of erosion rates for monoculture plots or non-legume-based crop rotation plots (typical of many conventional farming systems) versus legume-based crop rotation plots (typical of organic farming systems) have indicated a significant reduction in soil erosion due to legume-based crop rotations[23-25]. The benefits from green-manuring with a legume crop and reducing tillage operations could be included in the conventional farming system as well as a reduced level of commercial fertilizers. If conventional farming methods are not modified, the loss of valuable Naff topsoil will continue.

We thank Arnold Clausen and Donald Lambert for donating the use of their farms for this study. We also thank D. F. Bezdicek, R. A. Black, A. J. Busacca, D. J. Mulla and R. I. Papendick for reviewing this article.

Received 20 July; accepted 7 October 1987.

1. Bidwell, O. W. *J. Soil Wat. Conserv.* **41**, 317-320 (1986).
2. Papendick, R. I., Elliott, L. F. & Dahlgren, R. B. *Am. J. Altern. Agric.* **1**, 3-10 (1986).
3. Vereijken, P. *Neth. J. Agric. Sci.* **34**, 387-393 (1986).
4. Clancy, K. L. *Am. J. Altern. Agric.* **1**, 11-18 (1986).
5. US Department of Agriculture *Report and Recommendations on Organic Farming* (US Government Printing Office, Washington, 1980).
6. Jenny, H. *Factors of Soil Formation* (McGraw-Hill, New York, 1941).
7. Soil Conservation Service and Washington Agricultural Experiment Station. *Soil Survey of Spokane County, Washington* (US Dept Agriculture, US Government Printing Office, Washington, 1968).
8. Bolton, H. Jr, Elliott, L. F., Papendick, R. I. & Bezdicek, D. F. *Soil Biol. Biochem.* **17**, 297-302 (1985).
9. Lockertz, W., Shearer, G. & Kohl, D. H. *Science* **211**, 540-547 (1981).
10. Oelhaf, R. C. *Organic Agriculture* (Allanheid, Osmun, Montclair, 1978).
11. Allison, F. E. *Soil Organic Matter and Its Role in Crop Production* (Elsevier, New York, 1973).
12. Johnston, A. E. *Soil Use Mngt* **2**, 97-105 (1986).
13. Lynch, J. M. *J. gen. Microbiol.* **126**, 371-375 (1981).
14. Molope, M. B., Grieve, I. C. & Page, E. R. *J. Soil Sci.* **38**, 71-77 (1987).
15. Weilgart Patton, A. G. thesis, Washington State Univ. (1982).
16. Soil Conservation Service, Forest Service, and Economics, Statistics and Cooperatives Service *Palouse Co-operative River Basin Study* (US Dept of Agriculture, Washington, 1979).
17. Soil Conservation Service in cooperation with Washington State University Agricutural Research Center *Soil Survey of Whitman County, Washington* (US Dept of Agriculture, US Government Printing Office, Washington, 1980).
18. Schertz, D. L. *J. Soil Wat. Conserv.* **38** 10-14 (1983).
19. Uhland, R. E. *Crop Yields Lowered by Erosion* (USDA-SCS-Tech. Paper-75, USDA Soil Conservation Service, Washington, 1949).
20. McDaniel T. A. & Hajek, B. F. in *Erosion and Soil Productivity* (ed. McCool, D. K.) 48-58 (American Society of Agricultural Engineers, St. Joseph, 1985).
21. Busacca, A. J., McCool, D. K., Papendick, R. I. & Young, D. L. in *Erosion and Soil Productivity* (ed. McCool, D. K.) 152-168 (American Society of Agricultural Engineers, St. Joseph, 1985).
22. Young, D. L., Taylor, D. B. & Papendick, R. I. in *Erosion and Soil Productivity* (ed. McCool, D. K.) 130-142 (American Society of Agricultural Engineers, St. Joseph, 1985).
23. Miller, M. F. & Krusekopf, H. H. *The Influence of Systems of Cropping and Methods of Culture on Surface Runoff and Soil Erosion* (Bull. 177, Missouri Agriculture Experimental Station, Columbia, 1932).
24. Jamison, V. C., Smith, D. D. & Thornton, J. F. *Soil and Water Research on a Claypan Soil* (Techn. Bull. 1,379, Agricultural Research Serivce, US Dept Agriculture, US Government Printing Office, Washington, 1968).
25. Russell, E. W. *Soil Conditions and Plant Growth* (Longman, London, 1973).
26. Reeve, R. C. in *Methods of Soil Analysis, Part 1* (ed. Black, C. A.) 466-476 (Am. Soc. Agron., Madison, 1965).
27. Brink, R. H. Jr, Dunbach, P. & Lynch, D. L. *Soil Sci.* **89**, 157-166 (1960).
28. Metting B. & Rayburn, W. R. *Soil Sci. Soc. Am. J.* **47**, 682-685 (1983).

A behavioural method for accelerating re-entrainment of rhythms to new light–dark cycles

N. Mrosovsky & Peggy A. Salmon

Departments of Zoology, Psychology and Physiology, University of Toronto, Toronto, Ontario M5S 1A1, Canada

The idea of ameliorating jetlag with drugs has received considerable attention. Melatonin has been found to reduce feelings of jetlag in people after transatlantic flights[1]. In hamsters, injections of triazolam, a benzodiazepine, increase the rate of adjustment of activity rhythms to an 8 h advance of the light-dark (LD) cycle[2]. But melatonin can make people drowsy and triazolam often induces hamsters to run in their wheels[2,3]. Therefore, it is not clear whether these chemicals exert their chronotypic effects by acting directly on circadian pacemakers or because they first alter behavioural states. Non-photic behavioural events (for instance, social interactions) are capable of entraining rhythms and causing phase shifts[4]. Thus, it is possible that behavioural events alone could alter the rate of adjustment to new LD cycles. To investigate this possibility, we studied the rate of re-entrainment of hamsters in a testing paradigm similar to that used with triazolam[2]. We found that the rate of adjustment could be more than doubled simply by making the animals active on a single occasion in the middle of their normal rest period, immediately after the shift in the LD cycle.

Male hamsters (*Mesocricetus auratus*, LVG Charles River, Montreal, aged 95 days on the day of the first test) were kept in cages containing activity wheels[5]. They were housed in a room with a cycle of 14 h light and 10 h dark. Illumination in the cages during the light period was ~100 lux, as measured with a Gossen Lunasix light meter. During the dark period there was dim red illumination of about one lux. To accustom the animals to these conditions, they were kept in cages with activity wheels for ten days, and in the LD cycle for 30 days before test 1. After stable entrainment was obtained, all animals were subjected to an 8 h phase advance in the LD cycle, starting with an advance in the onset of darkness. Half the animals ($n = 10$) were left undisturbed. The other half ($n = 10$) were removed from their cages 1 h after the new onset of darkness and confined to running wheels. These wheels were not the same ones as used in the home cages, were clean, and were located in a different part of the room. After 3 h, the animals were returned to their home cages. Note that this was not a periodic daily event but occurred only on the day of the shift in the LD cycle.

Twenty days later, when all animals had adjusted their activity to the new LD cycle, the procedure was repeated, using the animals that had been undisturbed in the first test as the test animals; those animals that were confined to running wheels in test one were left undisturbed. The only other difference was that six days before the second test, the red lamps were removed, making the dark period totally dark. Manipulations were carried out with the aid of an infrared nightscope.

All the test animals ran vigorously when confined to the new wheels; they adjusted more quickly to the shift in the LD cycle than the controls (Fig. 1). Almost all of the control animals remained asleep or quiescent during the 3-h test period. To specify when resynchronization had occurred, we used the number of days required for an animal to begin its wheel-running within 30 min. of the onset of darkness on the new LD cycle, as in ref. 2. Undisturbed animals took about 8.5 days for re-entrainment while those that had the additional 3 h wheel running took only 1.5 days (Table 1). But the control animals adjusted faster in test 1, when the dim red light was present throughout. Age, experience and changing susceptibility to disturbance from neighbours that had already phase-shifted are other factors that might be involved. Whatever the explanation, in both tests, the experimental animals adjusted far more quickly

Table 1 Days taken to resynchronize (mean ± s.e.m.)

	n	Undisturbed	3 h extra activity	P*
Test 1	10	5.4 (±0.67)	1.6 (±0.31)	<0.01
Test 2	10	11.6 (±0.73)	1.5 (±0.17)	<0.01
Total	20	8.5 (±0.86)	1.6 (±0.17)	

* Two-tailed t-test.